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Metrology for Fair Trade and Resource Efficiency: Accurate Mass Measurements in Industrial Weighing Systems

VNIIM has ensured metrological traceability for heavy-duty weighing instruments through national standards, force-based methods, and an updated verification practice

*D. I. Mendeleyev Institute for Metrology (VNIIM)
Russia (RU)*



The Challenge

In the Russian Federation, high-capacity weighing instruments are widely used for commercial accounting, transport logistics, industrial process control, and settlement transactions. Wagon and road weighbridges are used for fertilizer shipments and petroleum-product logistics, while hopper scales are essential for batching and material-balance control in metal production.

An indicative industry estimate suggests that approximately 10 000 to 15 000 high-capacity weighing systems may be in operation across Russia, with at least several thousand of them used in applications subject to state regulation of assurance of measurement uniformity. This estimate should be treated as indicative, as no single public register distinguishes active high-capacity instruments by application and legal-metrology status.

Even small systematic errors in such measurements can cause significant commercial discrepancies, disputes between suppliers and customers, inefficient use of raw materials and energy, and unreliable production accounting. Where these instruments are used for legally regulated measurements, verification must provide metrological traceability to national standards and demonstrate conformity with mandatory metrological requirements.

The Solution

VNIIM has developed the scientific, methodological, and metrological basis for verification of high-capacity weighing instruments through a sustained programme of research and experimental-development work. Initial experimental development and validation of modular force-based methods for platform scales were carried out from 2017 to 2019. Further research in 2021 established the metrological requirements for force standards used to verify heavy-duty weighing instruments. It demonstrated that the uncertainty and maximum permissible errors of the force standards are sufficiently smaller than the applicable maximum permissible errors of the weighing instruments, thereby providing the required accuracy ratio for verification. Additional research in 2023 extended the methodological basis and practical application of non-weight-based verification approaches for industrial weighing systems.

Since 2022, the national verification framework for mass measurements has provided a basis for the use of direct and indirect measurement methods with transportable verification devices for applicable high-capacity weighing instruments. In direct measurement methods using reference weights, the indications of the weighing instrument, expressed in kg, are

compared directly with the nominal mass values of the reference weights, also expressed in kg. In the force-based indirect method, the indications of the weighing instrument, expressed in kg, are compared with mass values calculated from a metrologically traceable force value according to $m = F/g$, where F is the applied force, expressed in N, and g is the local acceleration due to gravity. A comparison of conventional verification using reference weights to a force-based verification using a transportable standard is provided in **Table 1**.

The force-based method enables a metrologically traceable force to be applied directly to load cells or load-receiving structures. The resulting force value is converted into the corresponding mass value using the local acceleration due to gravity. The method is applied as an alternative or complementary verification procedure where it is specified in the approved verification method and the type-approval documentation for the specific instrument.

This work is conducted in the field of legal metrology and supports legally valid verification of measuring instruments used in applications subject to state regulation of assurance of measurement uniformity. It is implemented with metrological traceability to national standards, suitable reference equipment, approved verification procedures, and documented conformity with mandatory metrological requirements.

A Quantifiable Impact

Experimental studies on a four-load-cell platform scale compared conventional loading with 30 t¹ of reference weights and modular force-based loading of the same load cells. The difference between the results obtained by the two approaches was less than 6 kg over the range from 0 to 30 t. The observed agreement demonstrates that, for the investigated configuration, modular force-based loading provided results consistent with those obtained by conventional reference-weight loading. **Figure 1** illustrates the two procedures. Notably, at high capacities, handling and positioning large quantities of reference weights using the conventional reference-weight loading can be a major practical constraint.

For rail-type wagon scales, a transportable verification standard applies a load of up to 12.5 t to each rail load cell. Sequential loading of eight rail load cells enables verification of wagon scales with capacities of up to 200 t. A comparison with conventional verification using reference weights showed a difference of no more than 10 kg over the range up to 50 t. The transportable standard achieved a relative error of no more than 0.02 %. Depending on site conditions, access to load cells, safety arrangements, and operational schedules, the procedure can reduce on-site verification time from several days to several hours and may be performed between train movements. For suitable rail-type instruments, the method can

¹ The unit symbol t has been retained throughout the text for high-capacity loads, while kg is used for the absolute differences between results. This is intended to follow established metrological practice for high-capacity weighing instruments and to avoid ambiguity between the metric tonne and the imperial ton.

thus reduce reference-weight handling and may be scheduled within available railway operating intervals.

Table 1. A comparison between the four-step procedure for conventional verification with reference weights and a force-based verification using a transportable standard.

Conventional verification with reference weights	Force-based verification using a transportable standard
1. Transport a verification wagon, lifting equipment, and reference weights to the site	1. Calibrate the force-measuring element against a national or higher-level force standard
2. Apply reference weights to the rail weighbridge in prescribed loading steps	2. Install transportable force-loading devices at the rail load cells
3. Compare the indications of the weighing instrument with the nominal mass values of the reference weights	3. Apply a controlled force to the rail load cells and calculate the equivalent mass using $m = F/g$
4. Record the indications at each loading point, evaluate errors, remove the reference weights, and restore normal operation	4. Record the response of each load cell, evaluate errors, remove the force-loading equipment, and restore normal operation



Figure 1. Comparative verification of a four-load-cell road weighbridge. Conventional verification of an experimental platform scale is illustrated by loading the platform with 30 t of reference weights, combined with monitoring of the four weighing channels. The same load cells were subsequently calibrated on force-reproducing machines. The difference between the results obtained by conventional mass loading and modular force-based loading was less than 6 kg over the range from 0 to 30 t.



Figure 2. Verification of rail-type wagon scales: conventional and force-based methods. Reference weights used for conventional verification of wagon scales are shown on the left. The inset shows a rail load cell loaded by a transportable force-based verification standard with a nominal load of up to 12.5 t. Sequential loading of eight rail load cells enables verification of wagon scales with capacities of up to 200 t. Comparison with conventional reference-weight loading showed a difference of no more than 10 kg over the range up to 50 t.

The extent of logistical and operational interruptions for conventional verification with reference weights depends on the mass of the reference loads, lifting arrangements, access conditions, and site operating requirements. For force-based verifications, the extent of logistical and operational interruption depends on access to the load cells, installation of the force-loading equipment, safety arrangements, and the approved verification procedure.

For road and wagon weighbridges used in fertilizer and petroleum-product logistics, improved traceability supports fairer commercial accounting by reducing the risk of unjustified over-delivery or under-delivery. For hopper scales in metal production, it improves batch control, material balance, and resource efficiency. The methods therefore support reliable legally regulated measurements, fair commercial transactions, efficient industrial infrastructure, and more sustainable production and logistics in the fertilizer, petroleum-product, and metal-production sectors.

POC: Ilya Shmigelskiy, i.y.shmigelskiy@vniim.ru